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## A valve

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(72) Inventor(s)
**Michael John Wilmott**

(73) Proprietor(s)
**Lambda Controls**
**International Inc**

**(Incorporated in the United Kingdom)**

**Canon House**
**20 Hamilton Way**
**Oakham Business Park**
**Mansfield**
**Nottingham**
**NG18 5BU**
**United Kingdom**

(74) Agent and/or
Address for Service
**Eric Potter Clarkson**
**Park View House**
**58 The Ropewalk**
**Nottingham**
**NG1 5DD**
**United Kingdom**

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FIG. 1

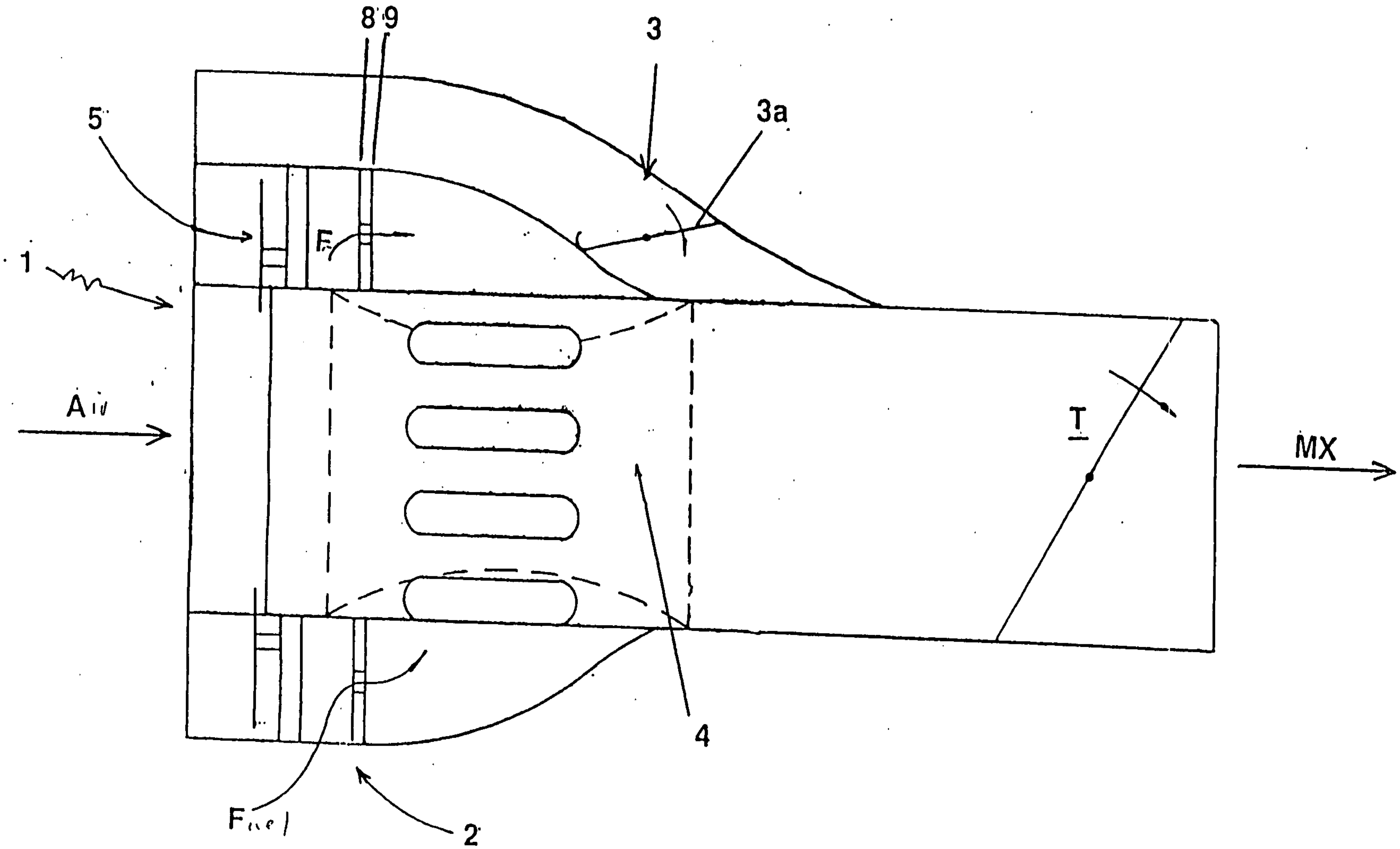


FIG. 2

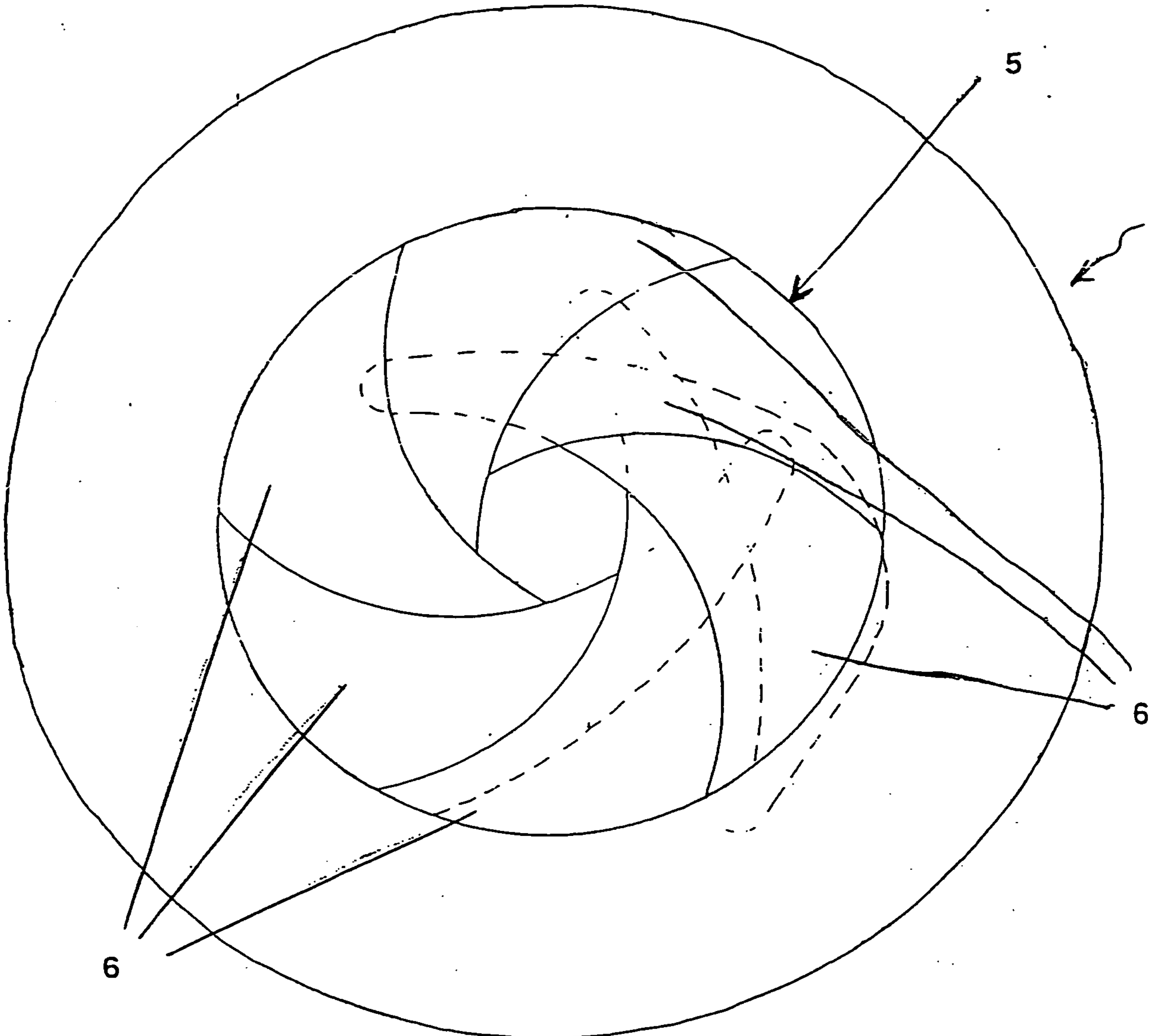



FIG. 3

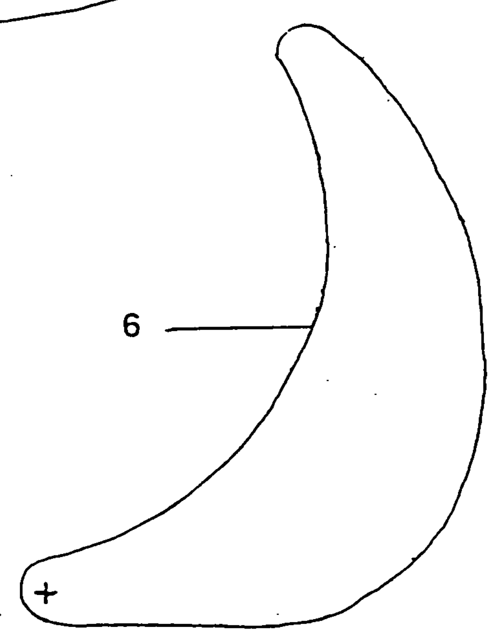


FIG. 4

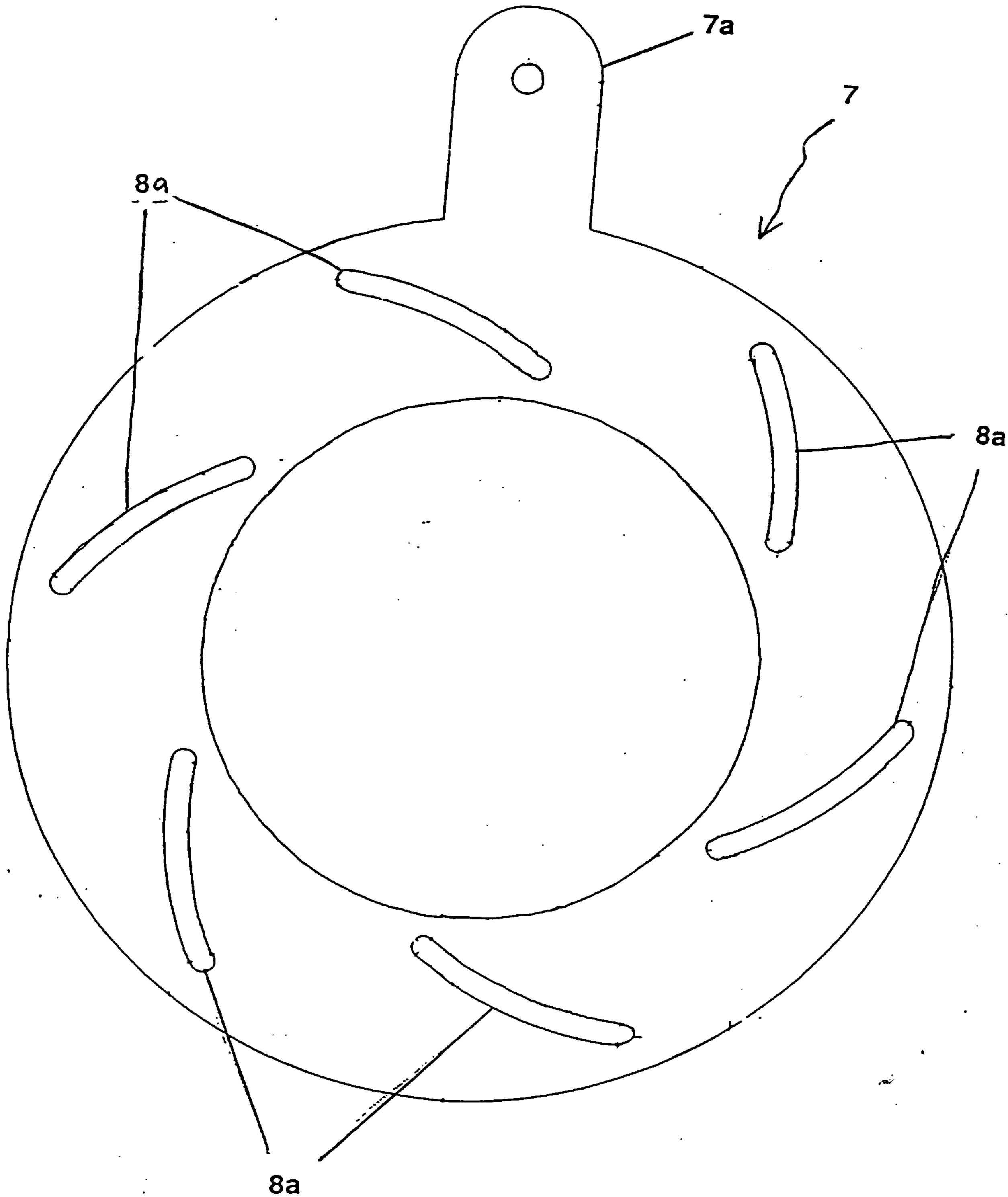


FIG. 5

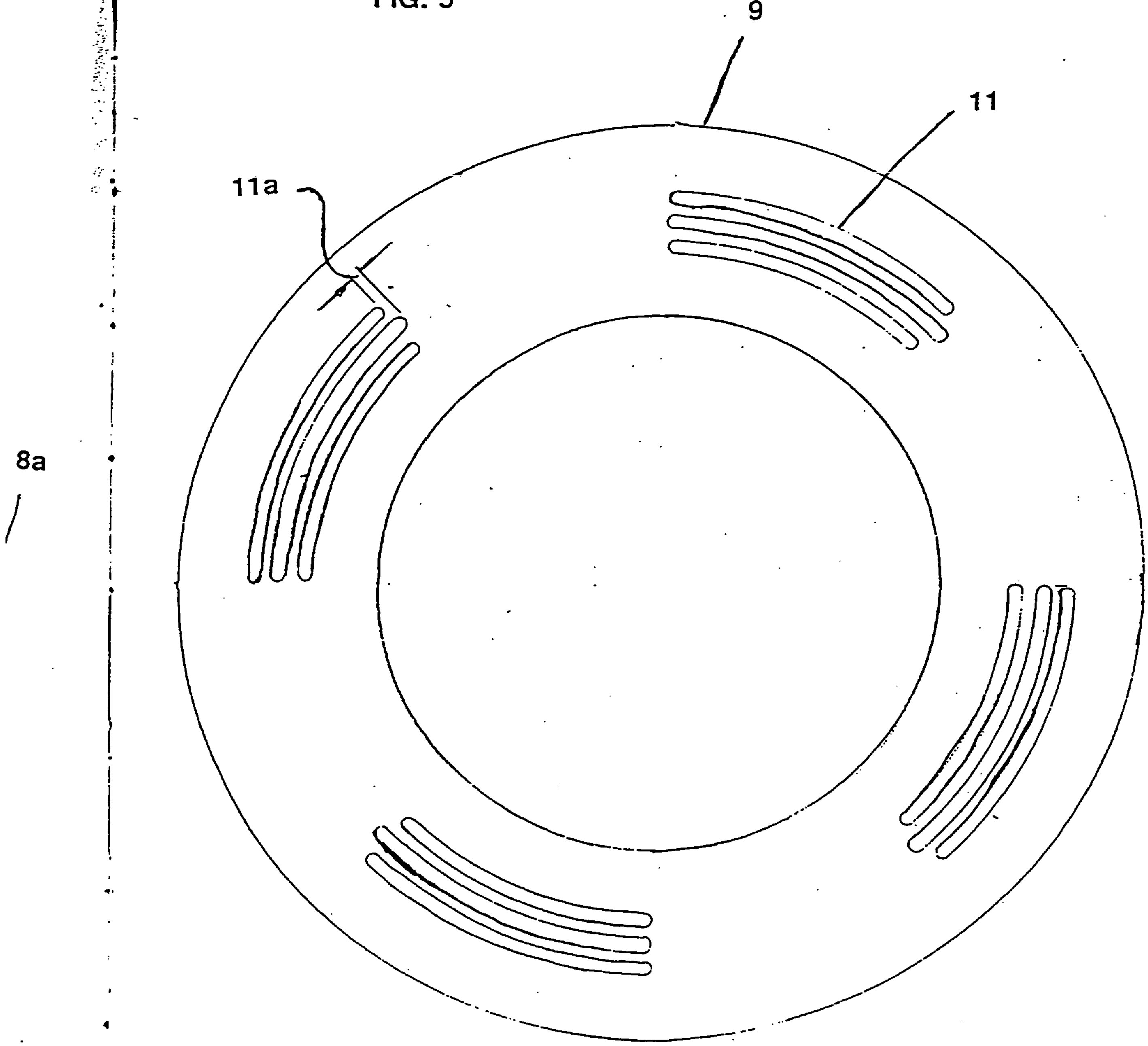


FIG. 6

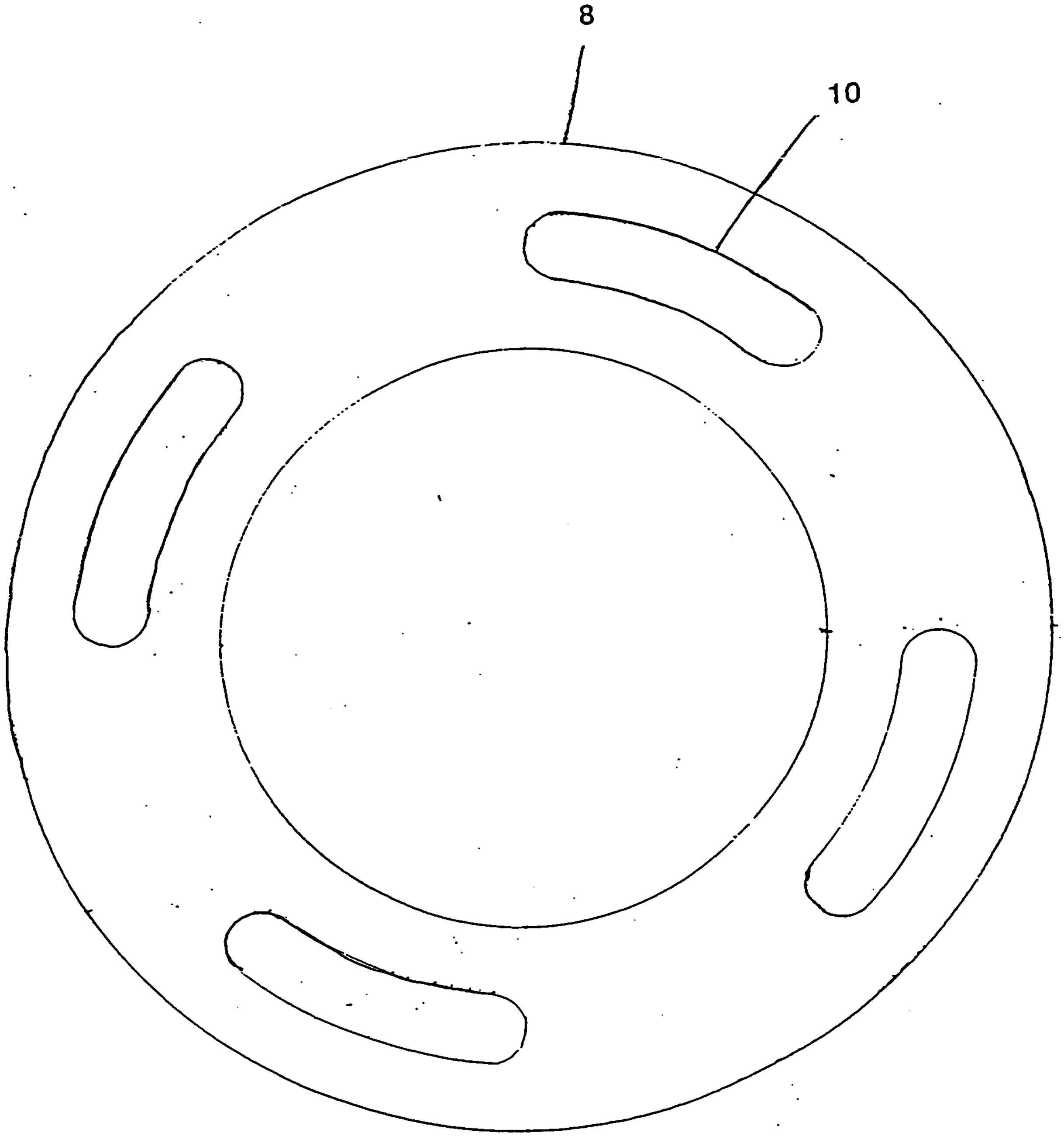


FIG. 7

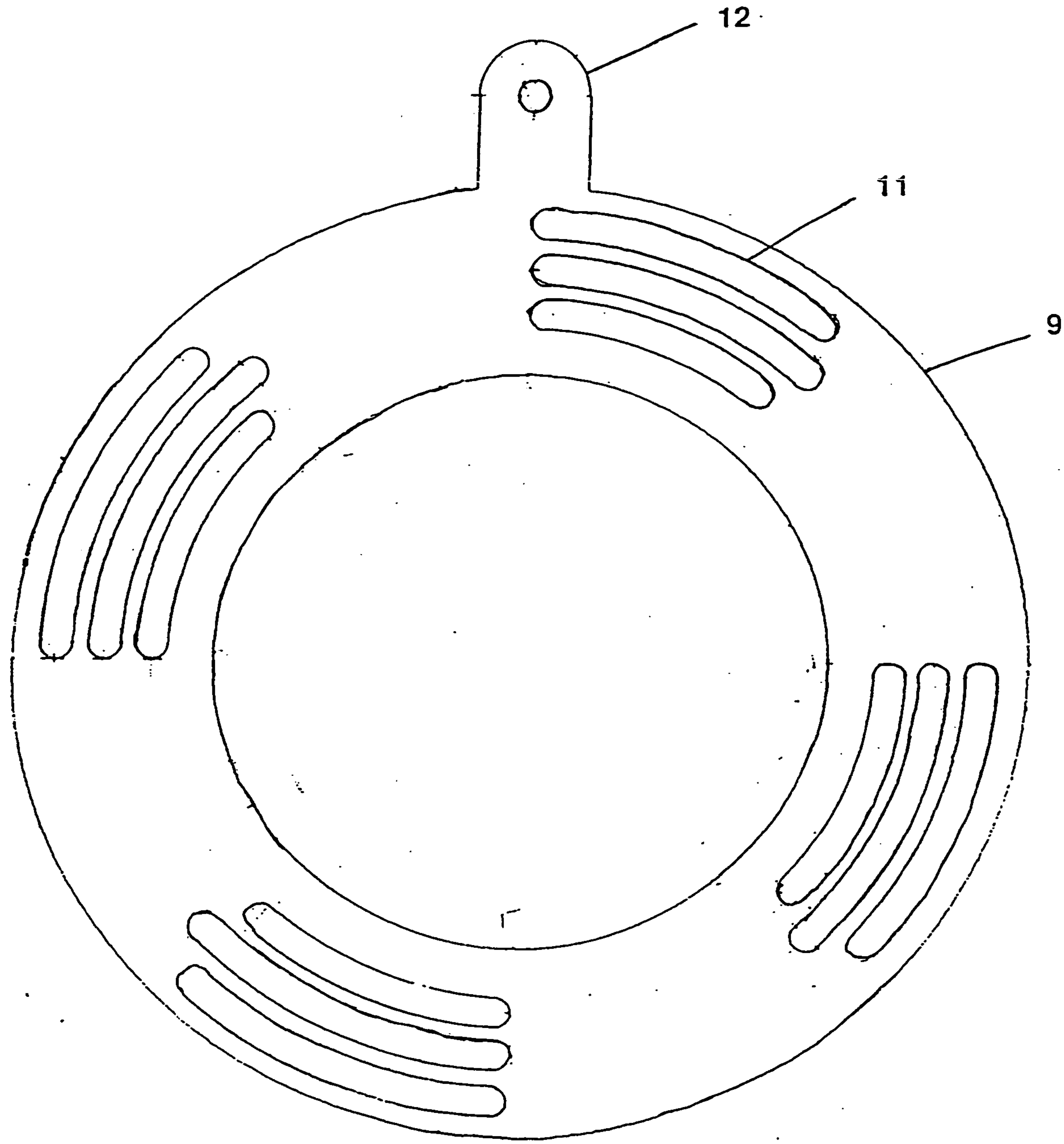
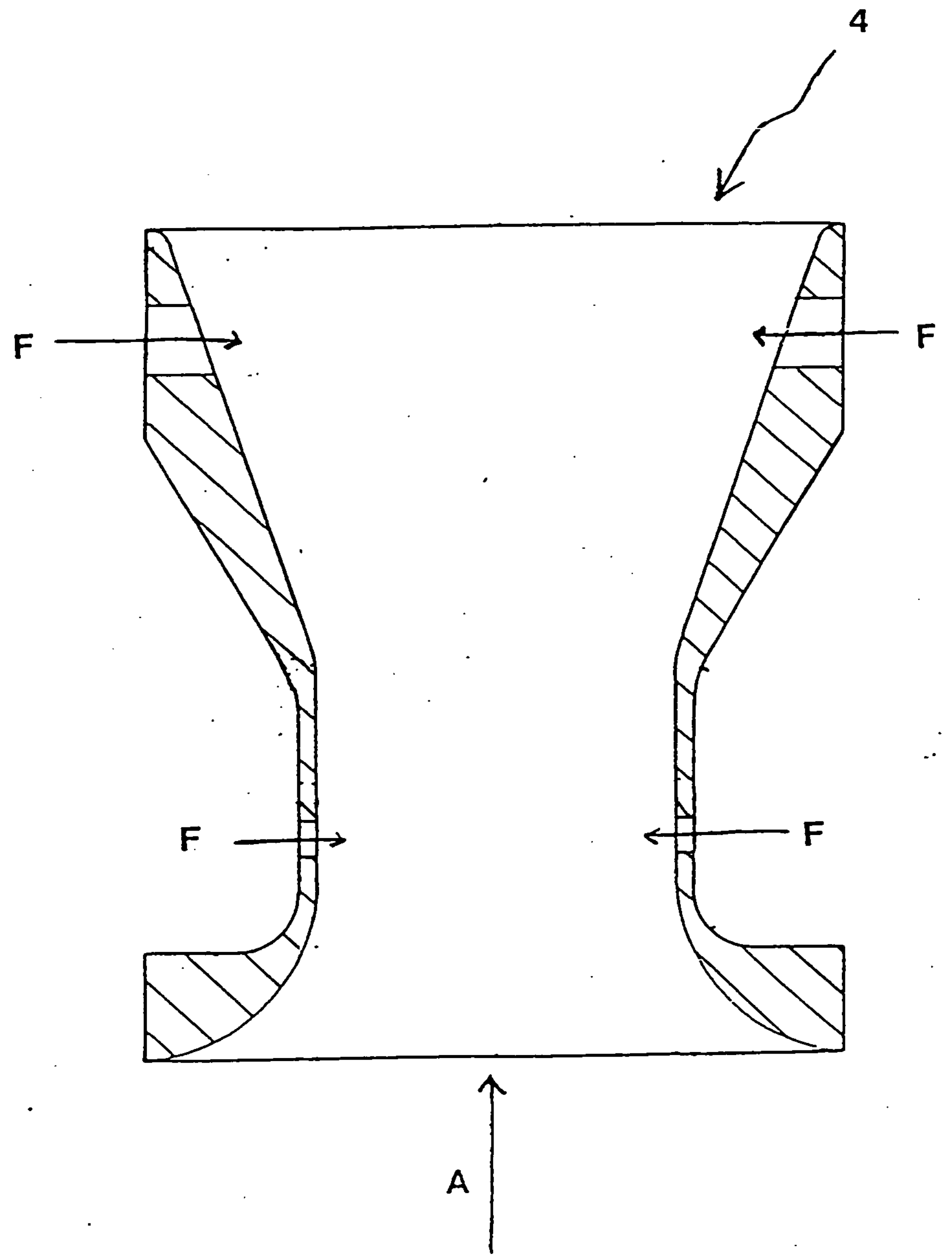


FIG. 8



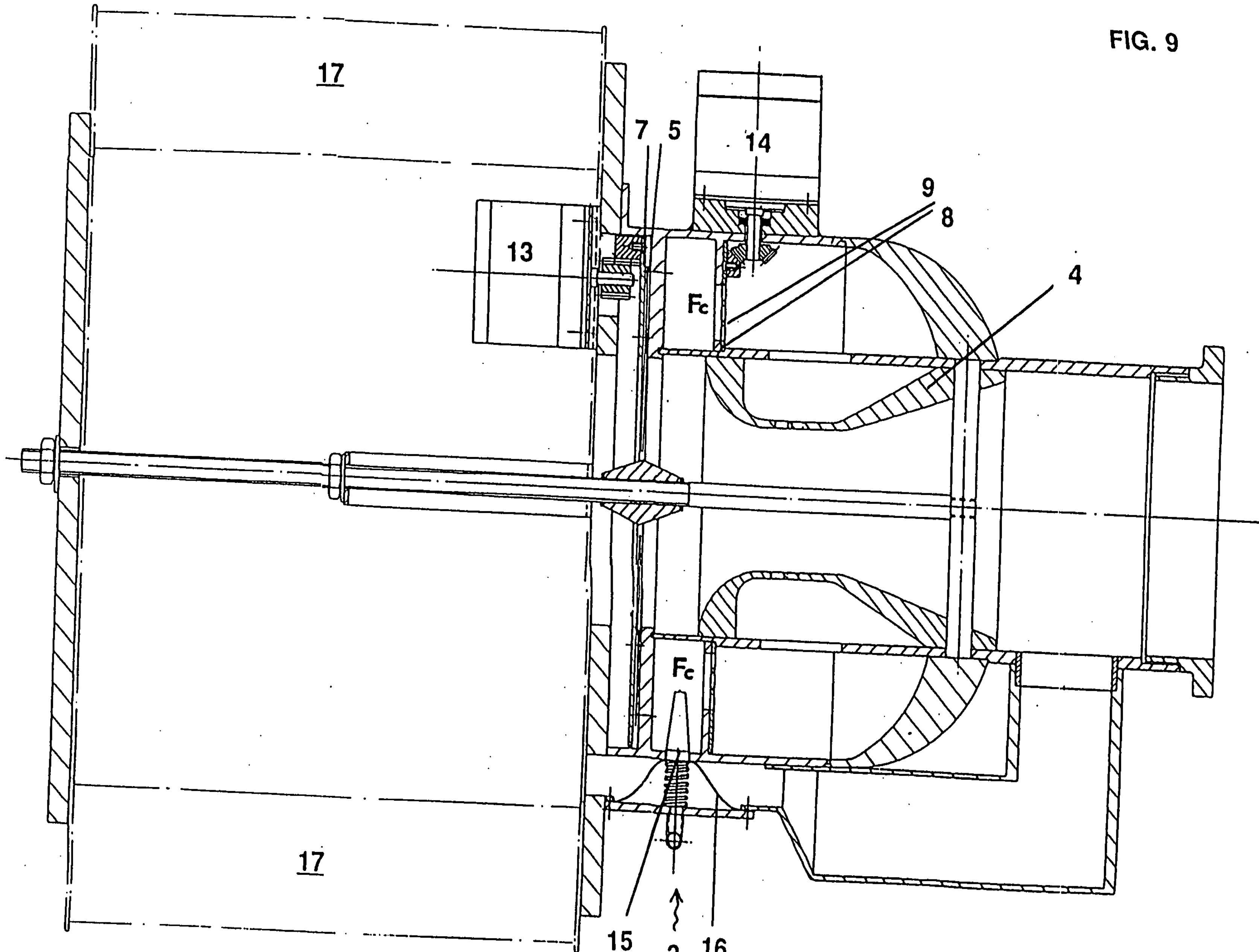



FIG. 9

# A VALVE

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The present invention relates to a valve and in particular to a control valve for an engine. The valve of the invention is especially suitable for engines which run on gaseous fuels such as methane.

It is known to use an air/fuel intake control device, or carburettor, in engines which run on gaseous fuel such as methane produced on land-fill sites. Such engines are used to drive a turbine to generate electricity.

Known carburettors only enable the engines to work effectively if supplied with a gaseous fuel, such as natural gas, whose richness does not vary significantly.

Conventional carburettors fitted to engines on land-fill sites allow the engines to run satisfactorily at methane levels of 50% + or - 5 to 10%, preferably + or - 2.5%. Outside these ranges the control of the air to fuel ratio afforded by the carburettor becomes inadequate.

If the methane level falls below the lower limit of this working range the engine will not work properly and must be switched off until the fuel levels rise to the narrow working range. If the methane level exceeds the upper limit of the working range, methane is flared off until its level falls within the working range.

Clearly, this action is unsatisfactory in terms of lost revenue and environmental damage.

The above problem is very serious on landfill sites where the levels of methane in the evolved gases (known as "sour" gas) may fluctuate a great

deal over time.

It has been proposed that the problems associated with low fuel levels could be overcome by increasing the pressure of the gaseous fuel in the carburettor. However, such an approach does not work because it does not increase the proportion of fuel in the mixture.

All gaseous fuels require a particular air to fuel ratio for combustion. For example, the combustion equation for methane is as follows:

$$CH_4 + 2O_2 \rightleftharpoons 2H_2O + CO_2$$

Assuming that air comprises 21% oxygen, to burn 0.0283m³ (one cubic foot) of methane requires 0.2694m³ (9.52 cubic feet) of air, that is,

$$\frac{0.0566\text{m}^3\ (2\ \text{Ft}^3)O_2}{0.0059\text{m}^3\ (0.21\ \text{Ft}^3)O_2\ \text{per}\ 0.0283\text{m}^3\ (\text{Ft}^3)\ \text{air}} = 0.2694\text{m}^3\ (9.52\ \text{Ft}^3)\ \text{air required.}$$

If all the heat generated from burning one cubic foot of methane is recovered the high heat value is 1073 kilojoules (1012 Btu). Subtracting the heat lost through vaporization of water 107 KJ (101 Btu) gives a low heat value of 966 kJ (911 Btu).

The low heat value represents the energy from methane that is available to drive the engine. However, the engine cannot utilise the full low heat value of the fuel. Instead, it utilises the low heat value of the air/fuel mixture. Natural gas (NG) comprises approximately 95% methane and has a low heat value of 959 kJ (905 Btu). The amount of energy actually available to drive the engine in the air/fuel mixture can be determined as follows:

$$\frac{959\text{ KJ } 0.0283\text{m}^3\ (905\text{ Btu Ft}^3)}{0.0283\text{ m}^3\ (1\text{ Ft}^3)\text{ NG} + 0.2694\text{m}^3\ (9.52\text{ Ft}^3)\text{ air}} = 91.2\text{ KJ per } 0.0283\text{ m}^3\ (86\text{ Btu per Ft}^3)\text{ air/fuel mixture} \quad (1)$$

Landfill gas (LFG) produced on landfill sites comprises approximately 50% methane and has a low heat value of 477 kJ 0.0283m$^3$ (450 Btu.Ft$^3$) compared to a value of 959 kJ 0.0283m$^3$ (905 Btu.Ft$^3$) for NG. One would therefore expect LFG to provide approximately half as much engine output as NG. However, it is the heat value of the air/fuel mixture which is important.

NG has a kJ of 959 (Btu 905) and requires 0.2694m$^3$ (9.52 Ft$^3$) air for complete combustion. 0.0283m$^3$ (one cubic foot) of LFG only needs 0.1347m$^3$ (4.76 Ft$^3$) air for complete combustion. The actual energy available to drive the engine using LFG can be determined as follows:

$$\frac{477\text{ KJ } 0.0283\text{m}^3\ (450\text{ Btu.Ft}^3)}{0.0283\text{m}^3\ (1\text{ Ft}^3)\text{ LFG} + 0.1347\text{m}^3\ (4.76\text{ Ft}^3)\text{ air}} = 82.8\text{ KJ per } 0.0283\text{m}^3\ (78.1\text{ Btu per Ft}^3)\text{ air/fuel mixture} \quad (2)$$

When the values (1) and (2) for NG and LFG are compared, it is apparent that LFG provides 91% of the heat value provided by the air/fuel mixture when NG is used. Hence LFG is a valuable fuel source.

The present invention aims to provide a valve which does not suffer from the disadvantages of known carburettors and which can control the air/fuel mixture intake of an engine so that it can run on gaseous fuel sources even when the levels of fuel in the gas are low, and subject to frequent and significant fluctuations.

According to the invention there is provided a valve for controlling the air/fuel mixture supplied to an engine, comprising:

an air inlet, including first valve means adapted to vary the size of

air flow path through the air inlet;

a fuel inlet, including second valve means adapted to vary the fuel flow through the fuel inlet;

a sensor for monitoring the composition of exhaust gases emitted from the engine, the output of said sensor coupled to control the first valve means to vary the air/fuel mixture supplied to the engine;

a fuel sensor adapted to monitor the level of fuel in the fuel mixture supplied to the fuel inlet, and to thereby control said second valve means to control the fuel flow through the fuel inlet;

wherein the first valve means comprises an aperture and an iris comprising a plurality of shutters pivotable to increase or decease the size of the aperture, movement of the shutters being controlled by an actuator plate connected to one or more of the shutters.

The sensor is arranged to sense the composition of the air/fuel mixture indirectly by monitoring the exhaust gas emitted from the engine, and to operate the air inlet accordingly.

Preferably, operation of the actuator is dependent on the shape and length of a control peg crescent-shaped slots in the plate. The steeper and straighter the crescent, the faster acting the iris becomes, in other words

a small movement of the actuator causes a large movement of the iris. Preferably, the control peg crescent is curved more gradually so that a full movement stroke of the actuator is directly linked to the full movement of the iris between its fully open and fully closed position. The actuator could be linear, rotary, cable, or an hydrostatic actuator. Preferably the actuators' movement is controlled electrically.

The actuator is preferably an electrical stepper motor whose gears, preferably bevel gears, are connected to the iris actuator plate. Such an actuator is preferred because it can move the actuator plate very rapidly, thereby affording a very fine degree of control over the iris opening.

The iris controls the flow of air in relation to the oxygen content which is monitored in the exhaust gas. An $O_2$ sensor such as that produced by Bosch (RTM) is suitable for monitoring the $O_2$ content of the exhaust gas. Preferably the $O_2$ content of the exhaust gas, which is the $O_2$ left over from combustion, is indicated as a 4-20 milliamp signal which can be interpreted by a control processor. The control processor signals the actuator to open or close the iris to keep the excess oxygen at a predetermined level. For example, the predetermined excess oxygen level may be 6%. If the sensor detects levels above 6% $O_2$ it will signal to the control processor which in turn will signal the actuator to close the iris until the sensor detects 6% $O_2$. Conversely, if the sensor detects less than 6% $O_2$ in the exhaust gas it will signal the control processor which in turn signals the actuator to open the iris until the predetermined 6% oxygen level in the exhaust gas is reached.

The valve is also provided with a fuel level sensor, preferably a methane ($CH_4$) sensor such as that sold by Isotech Ltd. $CH_4$ level sensing can take many forms including infrared colorimetry, in which an

output signal to the control processor of 4-20 milliamps is generated for a $CH_4$ level change of 20% to 70%. A decreasing $CH_4$ level results in a decrease in milliamp output signal and vice versa. For example, at 20% $CH_4$ the output signal would be 4 milliamps, at 32.5% $CH_4$ 8 milliamps, at 45% $CH_4$ 12 milliamps, at 57.5% $CH_4$ 16 milliamps, and at 70% $CH_4$ 20 milliamps. The fuel sensor monitors the fuel levels in the fuel inlet and signals the control processor to open or close the second valve means as required.

Although when the engine is running normally the iris opening is controlled in relation to the $O_2$ level detected by the sensor in the exhaust gas, during start up of the engine this is not the case. During start up, the $O_2$ sensor will detect normal atmospheric levels of oxygen (approximately 20% $O_2$). In this situation the control processor overrides the signal from the $O_2$ sensor and takes a measurement of the $CH_4$ level via the $CH_4$ sensor. Based on this measurement the control processor signals the actuator to open the iris to a predetermined opening size to suit the air/fuel requirements. Once an engine speed above cranking has been attained the $O_2$ sensor takes over control of the iris opening.

In a preferred embodiment the second valve means opens increasingly during start up until the air/fuel mixture achieves stoichiometry, that is, the ratio of air to fuel for complete combustion of the fuel. Alternatively, the second valve means can be opened fully initially and closed gradually until stoichiometry is attained. A disadvantage with the latter method is that the instantly rich fuel mixture will not be combusted fully so unburnt fuel will be present in the exhaust gases and this may lead to engine damage due to afterburn.

In a preferred embodiment, the second valve means comprises two plates each having one or more apertures therein. The plates are superimposed so that by

moving the plates relative to one another the respective apertures can be brought into and out of alignment with one another. Movement of the plates is achieved by means of an actuator. It is preferred that the actuator is a stepper motor connected to one of the plates of the fuel inlet as described above for the actuator of the air inlet.

When the apertures are substantially out of alignment the fuel inlet is "closed" so that only a small amount of fuel passes through it. As the plates are moved relative to one another their apertures move increasingly into alignment and the fuel flow through the inlet increases to a maximum in the fully aligned position. Conveniently, one of the plates is fixed and the other is movable.

Depending on the particular application, it may be convenient to allow relative movement of the plates between pre-determined positions, for example, closed, partially aligned and fully aligned.

In use, the valve of the invention is preferably positioned between the air filter and a conventional venturi upstream of the inlet manifold of the engine.

The venturi is preferably selected according to the nature of the fuel supply. For example when LFG is the fuel, the venturi is selected to allow the engine to work at methane levels within a fixed range of 50% methane + or - 5%.

When the rate of change in demand or loading of the engine increases suddenly, the oxygen sensor may sense that the oxygen level in the exhaust gas is too high and so close the iris of the air inlet. However, a rapid influx of air and fuel is actually required in such circumstances to

satisfy the increased demand.

The effect of increased demand on the engine can be likened to the experience of driving along a road in a motor vehicle in top gear and encountering a steep hill. However, the present engine has no gearing arrangement to compensate for the increased demand on the engine whose operation is controlled entirely by the air/fuel mixture supplied to it.

As the rate of change in engine demand increases the speed of the engine decreases. If the air/fuel mixture supplied does not compensate for this, the engine speed decreases further until the engine is overloaded and stalls. As engine stalling can take place in 2 to 3 seconds from the application of increased demand, there is a need for some form of rapid compensation when the rate of change in engine demand increases.

To remedy the above problem, in another preferred embodiment the valve further comprises demand relief means operable to allow an influx of air and fuel in response to a sudden increase in the load or demand of the engine. Conveniently, the demand relief means comprises a relief inlet in the form of a relief valve which is normally biased in a closed position, the relief inlet being in communication with an air inlet and a fuel inlet when opened. Increasing the load of the engine suddenly causes the iris to move to a closed position and results in a decrease in manifold pressure. With a decrease in pressure the relief inlet opens to allow a rapid influx of air. As, the relief inlet is also in communication with a fuel inlet, fuel is drawn into the relief air flow.

The relief valve may be a butterfly valve, but it is preferred that it is a diaphragm which is normally resiliently biassed in the closed position.

Operation of the relief inlet results in a signal being sent to the control processor to signal the actuator to open the iris. As the rate of change in engine loading decreases, the pressure in the inlet manifold increases and the butterfly valve of the demand relief means is biassed into its normal closed position and the air and fuel inlet arrangements take over to afford a finer degree of control over the air/fuel mixture, so the engine can run at its optimum efficiency.

When the air and fuel are operated via stepper motor actuators, the response to changes in the rate of change of engine demand is so rapid that the above relief means can be dispensed with.

The valve of the present invention constitutes a major advance in the art because it allows the composition of the air/fuel mixture entering the inlet manifold to be controlled within the optimum efficiency range of the engine, even if the level of fuel in the fuel supply is low, or fluctuates considerably.

Although, particularly suitable for use in an engine running on LFG, it is envisaged that the valve of the invention could be used to control the composition of air/fuel mixtures in engines run on other fuels such as hydrogen or NG.

Preferred embodiments of the invention will now be described, by way of example only, with reference to the following drawings in which:

Figure 1 is a schematic section through a valve of the invention;
Figure 2 shows the iris of the air inlet;
Figure 3 shows an individual shutter of the iris;
Figure 4 shows the actuator plate for the iris;

Figures 5 and 6 show the plates forming the fuel gas inlet;
Figure 7 shows a plate of the fuel gas inlet;
Figure 8 shows a venturi; and
Figure 9 is a section through another valve of the invention.

The valve of the invention shown in figures 1 to 7 comprises an air inlet 1, a fuel gas inlet 2, an oxygen sensor, a $CH_4$ sensor (both not shown), and a relief inlet 3. In use, the valve is positioned between an air filter (not shown) and a conventional venturi 4 upstream of the inlet manifold of an engine.

The air inlet 1 comprises an aperture and an iris 5 for opening or closing the aperture. In form and operation, the iris 5 resembles that used on a camera, although it is, of course, much larger and more durable in construction. As shown in Figure 2 the iris comprises six shutters 6.

Operation of the iris 5 is controlled by an actuator plate 7. The actuator plate 7 is formed with six crescent shaped slots 8a, one for each shutter 6 of the iris 5. Each shutter 6 is pivotable on a control peg (not shown) which is located in a slot 8a of the actuator plate 7 in the assembled valve.

It will be apparent that rotation of the actuator plate 7 moves the control pegs along their respective slots 8a and causes them to pivot to increase or decrease the size of the iris opening, as shown in Figure 2. A cable actuator acts upon the arm 7a of the actuator plate 7 to bring about rotation.

The actuator plate 7 is connected via a control processor (not shown) to an oxygen sensor which monitors oxygen levels in the exhaust gases emitted from the engine.

If the composition of the air/fuel mixture is too lean, the sensor detects increased oxygen levels (for example more than a predetermined 6% $O_2$) in the exhaust gas and signals the control processor which in turn signals the actuator to rotate to close the iris 5, restricting the influx of air (A) and thereby increasing the level of fuel in the air/fuel mixture (to the predetermined 6% $O_2$ level). If the air/fuel mixture is too rich, the sensor detects this and signals the actuator so that the actuator plate is rotated in the opposite direction to open the iris and let more air flow in through the aperture of the air inlet to make the air and fuel mixture (MX) leaner.

As shown in Figures 5 and 6, the fuel gas inlet 2 comprises two plates 8, 9 each having apertures 10, 11 formed therein. The plates are superimposed and one of the plates 8 is fixed in the assembled valve so that rotation of the other plate 9 can bring the apertures 10, 11 of the two plates into alignment. The inflow of fuel gas is indicated by the arrows F in Figure 1.

As shown, the apertures 10, 11 in the plates 8, 9 of the gas inlet 2 are arranged so that they can be moved between positions in which they are substantially out of alignment; in partial alignment; or in full alignment. This movement is brought about by the action of a cable actuator (not shown) on the arm 12 of the plate 9.

When the apertures 10, 11 are substantially out of alignment the gas inlet 2 is "closed". However, a small amount of fuel can pass through because part 11a of the aperture 11 is always in alignment with the aperture 10, as shown in Figure 5.

During start up of the engine the apertures 10 and 11 are in full alignment. The control processor overrides the signal from the $O_2$ sensor

in the exhaust and signals the actuator to open the iris to a predetermined opening size in response to the level of fuel in the fuel inlet which is signalled by the $CH_4$ sensor.

When the engine fires and a speed above cranking is achieved the plate 9 is rotated by the actuator to bring the apertures into partial alignment, which is the optimum position to achieve efficient engine output at a given fuel level. If the level of fuel in the supply falls below a predetermined level the $CH_4$ sensor detects this and signals the control processor which in turn signals an actuator to rotate the plate 9 bringing the apertures into full alignment, the maximum opening of the fuel gas inlet 2.

It should be noted that the $CH_4$ sensor and $O_2$ sensor mediated controls of the air/fuel mixture composition are independent of one another apart from the start up conditions where the iris opening is set initially in response to the signal from the $CH_4$ sensor. The fuel inlet control and air inlet controls are therefore separate, but complementary control systems.

The butterfly valve 3a of the relief inlet 3 is normally biassed in the closed position shown in Figure 1. However, if there is a sudden increase in the rate of change in demand or loading of the engine, that is, when the engine's throttle (T) is opened to speed up the engine, the oxygen sensor may sense that the oxygen level in the exhaust gas is too high and signal the actuator to close the iris of the air inlet 1. To overcome this potential problem, the relief inlet 3 is arranged so that when iris 5 is in a closed position, the butterfly valve 3a of the relief inlet 3 opens to supply air rapidly. The relief inlet 3 also communicates with a small gas fuel inlet (not shown) when it is opened, so that fuel is also drawn into the relief air flow to satisfy the increased demand of the engine.

The relief inlet 3 is arranged so that on opening the butterfly valve 3a, a signal is sent to the control processor which in turn signals the actuator to open the iris 5 of the air inlet 1. As the rate of change in engine demand diminishes, the pressure in the inlet manifold increases. This causes the butterfly valve of the relief inlet 3 to be biassed into its normal closed position and the air and fuel gas inlet control arrangements 1 and 2 take over to afford a finer degree of control over the composition of the air/fuel mixture to allow the engine to run at optimum efficiency.

A preferred valve of the invention is shown in figure 9, and the reference numerals are the same as those used previously where the features are the same.

In this embodiment the actuator plate 7 of the iris 5 is rotated by an actuator in the form of a stepper motor 13 connected to the actuator plate by a spur gear arrangement, as shown. Similarly, the plate 9 of the fuel inlet 2 is rotated by an actuator in the form of a stepper motor 14 connected to the plate 9 by a bevel gear arrangement. Either gear arrangement is suitable, though the bevel gears are preferred.

In the embodiment of figure 9 the relief inlet comprises an air inlet which is normally prevented from communicating with the fuel chamber Fc by a relief valve 15 comprising a diaphragm 16 resiliently biassed in a closed position, as shown in figure 9.

In use, should the rate of change in engine demand increase suddenly and cause a decrease in pressure, the pressure of the air flow urges the diaphragm 16 against the bias so that fuel in the fuel chamber Fc can be drawn into the air flow. This action supplies a burst of air and fuel to prevent the engine from stalling before the $O_2$ and $CH_4$ mediated control

via the iris 5 and fuel inlet 2 responds to the change in engine demand.

It should be noted that the stepper motor actuators 13, 14 can function so rapidly that the relief inlet can be dispensed with. However, the incorporation of a relief inlet is beneficial for other actuator arrangements such as cable actuators which do not function as quickly as the stepper motors.

In use, the above valve of the invention is connected to an air filter 17 as shown in figure 9, with the stepper motor actuator of the iris housed inside the filter.

Although not limited to a particular fuel source, the valves of the invention are particularly suitable for use in engines operating on LFG evolved from landfill sites. For this application the size of venturi 4 is selected to operate effectively in the methane level range of 50% + or - 5%.

## CLAIMS

1. A valve for controlling the air/fuel mixture supplied to an engine, comprising:

an air inlet, including first valve means adapted to vary the size of air flow path through the air inlet;

a fuel inlet, including second valve means adapted to vary the fuel flow through the fuel inlet;

a sensor for monitoring the composition of exhaust gases emitted from the engine, the output of said sensor coupled to control the first valve means to vary the air/fuel mixture supplied to the engine;

a fuel sensor adapted to monitor the level of fuel in the fuel mixture supplied to the fuel inlet, and to thereby control said second valve means to control the fuel flow through the fuel inlet;

wherein the first valve means comprises an aperture and an iris comprising a plurality of shutters pivotable to increase or decrease the size of the aperture, movement of the shutters being controlled by an actuator plate connected to one or more of the shutters.

2. A valve as claimed in claim 1 wherein a shutter is pivotable on a peg located in a slot in the actuator plate.

3. A valve as claimed in claim 2 wherein movement of the peg along the entire length of the slot pivots the shutter from a closed to a fully opened iris aperture position.

4. A valve as claimed in claim 1 wherein the second valve means comprises at least two plates each having one or more apertures, the plates being moveable relative to one another to bring their respective

apertures into and out of alignment with one another to control the flow of fuel therethrough.

5. A valve as claimed in any preceding claim wherein the first valve means or the second valve means is operable by a stepper motor.

6. A valve as claimed in claim 1 wherein the sensor for monitoring the composition of exhaust gases emitted from the engine comprises an oxygen sensor.

7. A valve as claimed in claim 1 wherein the sensor for monitoring the level of fuel in the fuel mixture supplied to the fuel inlet comprises a methane sensor.

8. A valve as claimed in claim 6 wherein the oxygen sensor and fuel sensor mediated controls are independent of one another.

9. A valve as claimed in any preceding claim further comprising a relief inlet adapted, in use, to provide a rapid supply of air and fuel independently of said first and second valve means, in response to a sudden increase in the rate of change in engine demand.

10. A valve as claimed in claim 9 wherein the relief inlet includes a relief valve means which is normally biassed in a closed position.

11. A valve as claimed in claim 10 wherein movement of the relief valve means signals the first valve means to open.

12. A valve substantially as described herein with reference to the accompanying drawings.

13. An air/fuel supply system for an engine comprising a valve as claimed in any preceding claim, positioned between an air filter and a venturi.

14. An engine with the air/fuel supply system of claim 13 upstream of the inlet manifold.

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